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CORROSION PROTECTION OF 416 STAINLESS STEEL FIRING PROBES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The effectiveness of several protective coatings in resisting pitting corrosion on 416 stainless steel 152mm firing probes was investigated using an accelerated corrosion test. Test specimens with selected metallic and non-metallic coatings were immersed in ferric chloride and examined periodically for damage. This report concludes that on the basis of these tests, the non-metallic coatings investigated generally provided better resistance to corrosive attack than the metallic coatings investigated.

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INTRODUCTION

In September 1975, an analysis was conducted on a damaged 152mm firing probe (Figure 1). The probe was manufactured from 416 stainless steel and exhibited a considerable amount of pitting damage on its surface. Albeit stainless steels generally exhibit good corrosion resistance, pitting is a form considered intermediate between general corrosion and complete immunity.[1] Stainless steels (especially grades containing sulphur e.g., 416) while displaying relatively good resistance to general surface corrosion are particularly susceptible to pitting attack.

At this point, an investigation was undertaken into protective coatings as a possible measure to inhibit the pitting attack upon the 416 stainless steel firing probes. It is important to understand, however, that corrosion is a chemical reaction whose occurrence and rate are dependent upon a complex interaction of material and environmental variables such as alloying elements, surface finish, corrosive medium and concentration, temperature, time, pH, pressure, etc. Consequently, it is venturesome to attempt laboratory duplication of the corrosive conditions found in the field. Therefore, the actual service conditions re-

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[1] N.D. Greene and M.G. Fontana, Corrosion Engineering, McGraw-Hill, New York, 1967, p.50.

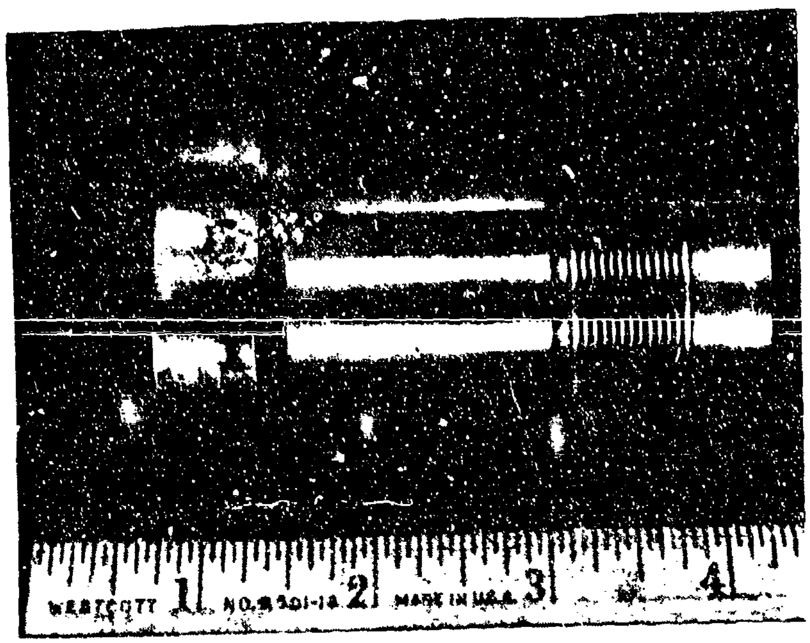

Figure 1. Damaged 152mm firing probe with sections cut out for metallographic analysis of pitting attack.

sponsible for the corrosive attack on the firing probes were not duplicated, but, instead, a typical pitting corrosion environment was created where the primary variable was the protective coating.

PROCEDURE

The following protective coatings were evaluated on 416 stainless steel:

Electroplated lead

Electroplated chromium

Electroplated nickel

Sandstrom 9A Dry Film Lubricant

Sandstrom 9A Dry Film Lubricant + Fe-phosphate undercoat

Sandstrom 26A Dry Film Lubricant

Sandstrom 26A Dry Film Lubricant + Fe-phosphate undercoat

In addition, 416 stainless as-finish machined (present condition of firing probe) was tested for a control situation. Actual testing consisted of immersing the test specimens (Figure 2) into a 10% solution of ferric chloride ($FeCl_3$) at room temperature; 10% $FeCl_3$ is an extremely aggressive pitting environment for stainless steels and was selected in order to accelerate the tests.[2]

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2. H. Ulig, Corrosion and Corrosion Control, John Wiley and Sons, 1963, p.272.

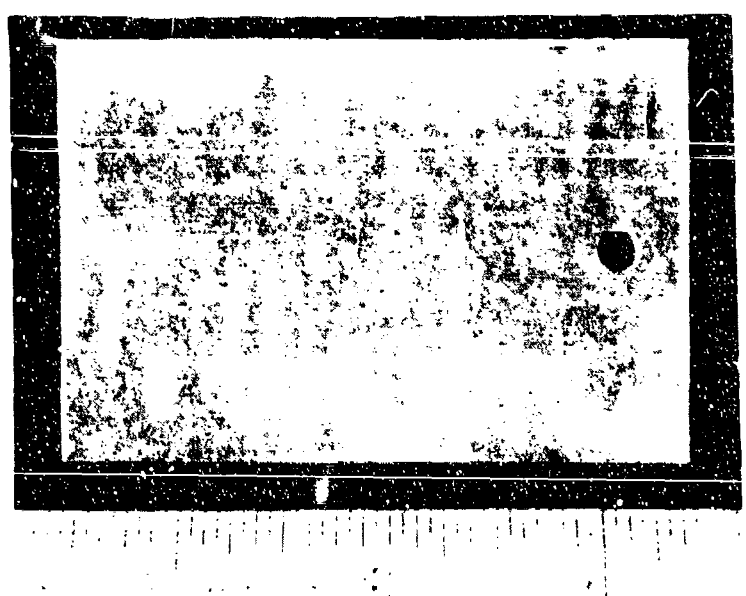

Figure 2. Corrosion test specimen 1.3X

Test specimens were machined from 416 stainless and finished to 2" x 3" x 1/8" thick plates. The surfaces were prepared by grinding with 120 grit abrasive followed by ultrasonic cleaning in acetone. They were passivated in a nitric acid-water bath (1:1) for two hours at room temperature. Following passivation, the specimen thickness was measured with a micromete Test specimens to be plated were then degreased electrolytically in a cleaning solution (KOH), plated and then measured again to determine the plate's thickness. All plating was done using two electrodes (anodes) an equal distance away from each side of the specimen (cathode) to assure a uniform buildup of plate on each side of the specimen (plating solution, voltage, current and time are given in Table I). The lead and chromium plating required a reverse etch before plating. The 9A dry film lubricant and iron phosphate coatings were applied by dipping, while the 26A was sprayed on. The 9A was cured at 400°F for one hour while the 26A required only overnight air drying. In the same manner as the plated specimens, the coated specimens were dimensionally checked before and after application of the dry film lubricants to determine the coating thickness.

The specimens were suspended vertically in the 10% $FeCl_3$ solution and were exposed for 25 hour time periods. At the end of each period, the specimens were removed and flushed with water followed by cleaning with alcohol to remove surface residue. Specimens were examined visually under low magnification (7X-35X) for evidence of corrosion or disparities in the plate/coating such as pits, blisters, cracking, or peeling. The solution was replaced with a fresh one and the specimens were immersed again for another 25 hour period. Peeling, cracking, pitting or any other evidence of an extensive breakdown in the protective coating was cause for discontinuing the test.

RESULTS AND DISCUSSION

The results of the testing are summarized in Table I and displayed in Figure 3. The 416 stainless steel specimen (uncoated) was attacked immediately and suffered extensive pitting damage. The surface condition of the sample before and after testing plus a profile through the pitting is shown in Figure 4. The chrome and nickel electroplates offered relatively little resistance (25 hrs) to the attack of the $FeCl_3$. Once the solution penetrated the coatings via cracks, surface disparities, etc., the 416 stainless underneath was attacked along the interface between the base metal and the coating. This kind of attack was extensive

TABLE I

Coating/Plating	Application	Thickness (Inches)	Corrosion Protection (Hours)
416 Stainless Steel	"No coating"	-	25
Nickel	Nickel chloride-Hydrochloric acid solution Plate: 2.8 amperes @ 3 volts, 1 hour	.0005	25
Lead	Pb $(BF_4)_2$ solution Reverse etch: 9 amperes @ 20 volts, 2 minutes Plate: 9 amperes @ 20 volts, 12 minutes	.002	225*
Chromium	Chromic acid-Sulfuric acid solution Reverse etch: 10 amperes @ 8 volts, 2 minutes Plate: 10 amperes @ 8 volts, 1.5 hours	.0005	25
9A Over Iron Phosphate	Iron phosphate dip, air dry 9A dip, air dry, cure @ 400°F for 1 hour	.001	250*
26A Over Iron Phosphate	Iron Phosphate dip, air dry 26A spray, air dry	.0005	125 hours
9A	9A dip, air dry, cure @ 400°F for 1 hour	.001	250*
26A	26A Spray, air dry	.0005	150 hours

Immersion, 10% $FeCl_3$ solution, 25-28°C, PH 1.5. *Test stopped prior to failure

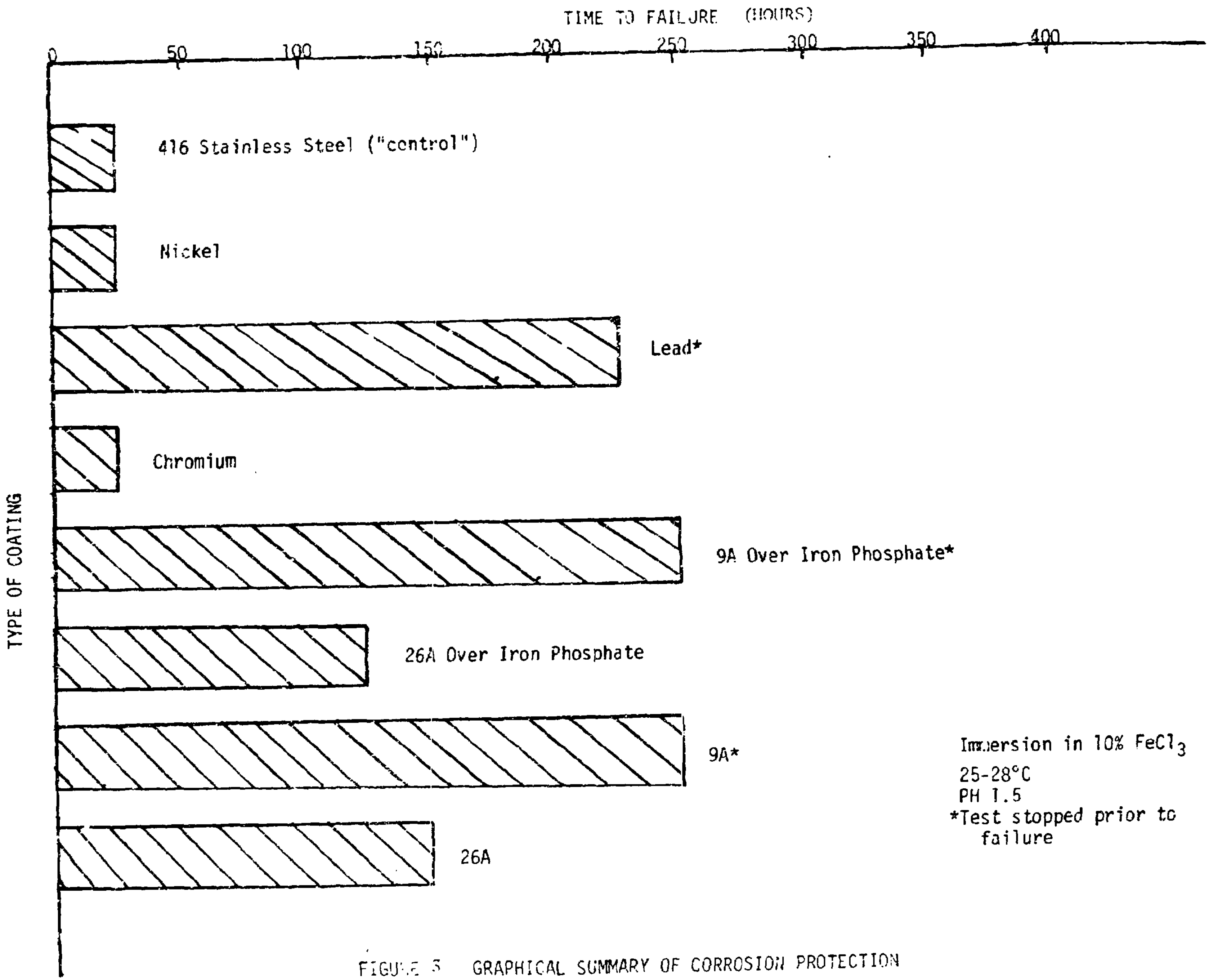

FIGURE 5 GRAPHICAL SUMMARY OF CORROSION PROTECTION

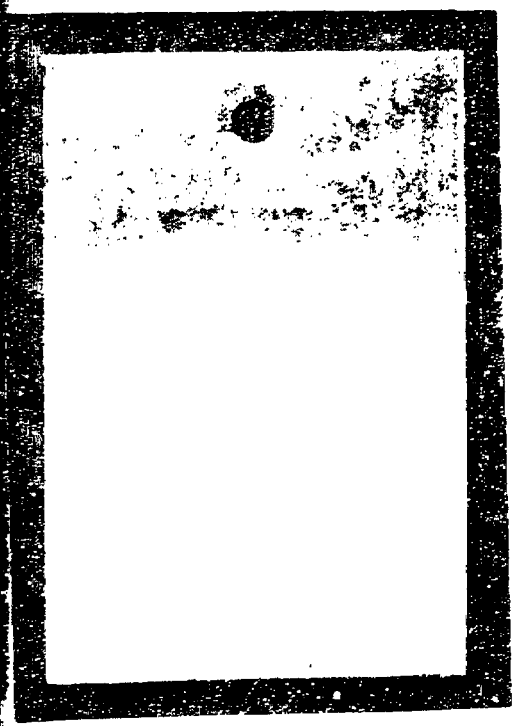

FIG. 4a. 416 Stainless Control Specimen after 25 hours. 1X

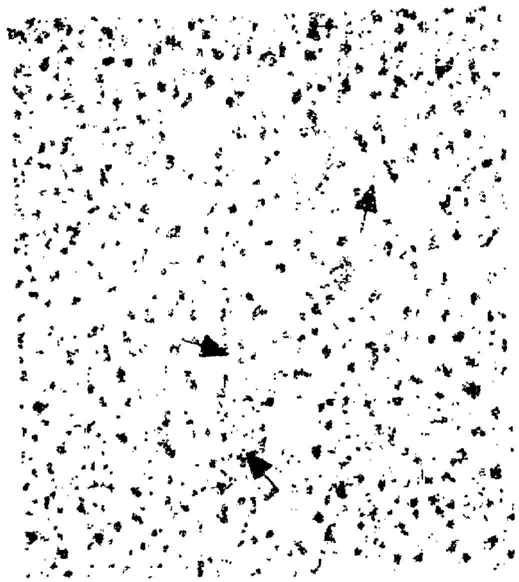

FIG. 4b. Close-up of Surface Attack. 10X

FIG. 4c. Photomicrograph showing severity of pit formation in specimen surface. 500X

in the Cr plated specimen as the entire Cr plate flaked and peeled off during cleaning. The nickel plate, which was not cleaned upon removing from solution, flaked in the same manner (Figure 5). Lead displayed a greater resistance to the $FeCl_3$ solution but eventually showed some signs of attack after 225 hours. In comparison with the other metallic coatings, the lead plate also exhibited greater resistance to undercutting at the interface (base metal/plating). It should be noted, however, that lead plate is relatively soft and ductile thereby offering very little abrasion resistance.

On the other hand, the dry film lubricants held up much better than the Ni or Cr plate. The 26A (air dry) provided adequate corrosion protection up to approximately 150 hours while the 9A (high temperature cure) was stopped at 250 hours with very little evidence of attack (Figure 6). These low friction coatings may be easily applied by dipping or spraying once the metal surface has been properly prepared. Although 26A requires only air drying, it does not have the wear resistant properties of the heat-curing 9A. The maximum operating temperatures for the 9A and 26A are 500°F and 300°F respectively. These maximum operating temperatures easily exceed the 152mm firing probe service temperature (reportedly 150°F).

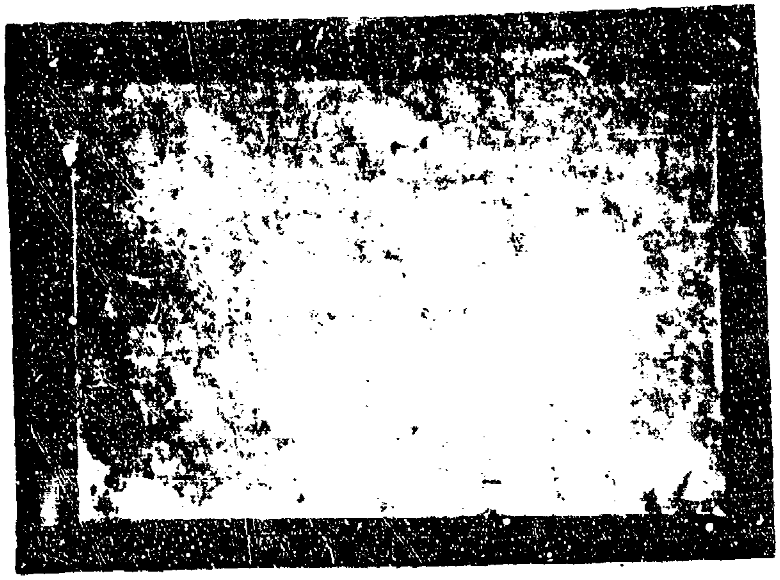

Figure 5. Nickel plate after 25 hours in 10% $FeCl_3$

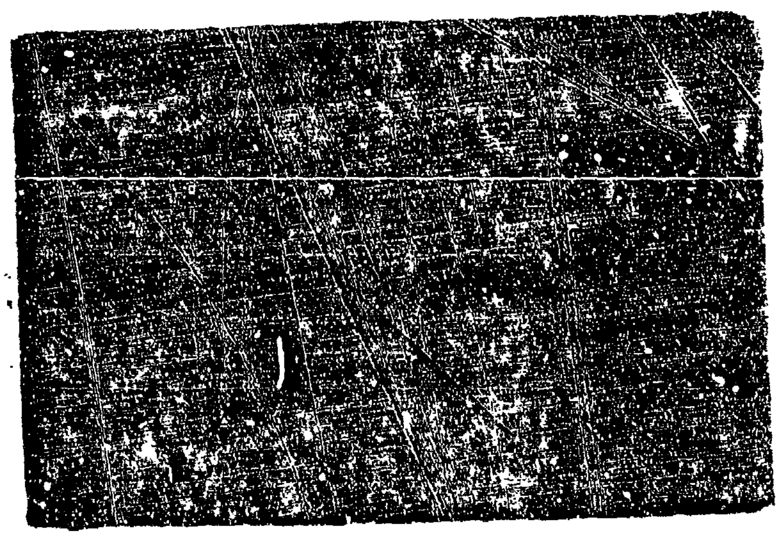

Figure 6. 9A Dry Film-Iron Phosphate after 250 hours in 10% $FeCl_3$

Two test specimens (26A, 9A) were treated with an iron phosphate undercoating, as this thin coating is an excellent base (primer) for paint and other ceramic coatings. This undercoating provided no additional resistance when 26A was applied over it. However, the 9A iron phosphate undercoat test specimen displayed slightly greater corrosion resistance than the untreated 9A specimen.

SUMMARY

The results of this experiment demonstrate that the dry film lubricants, especially Sandstrom 9A applied over iron phosphate, provided better pitting corrosion protection than the electroplated coatings. Although this conclusion is heavily influenced by the experimental conditions, the fact that it was an accelerated test utilizing an unusually aggresive medium, provides a measure of confidence that the 9A dry film (with the iron phosphate undercoating) will adequately protect the firing probe against pitting corrosion in service. As a result of this investigation, 9A dry film currently is being applied to 152mm firing probes with no reported failures to date (Figure 7).

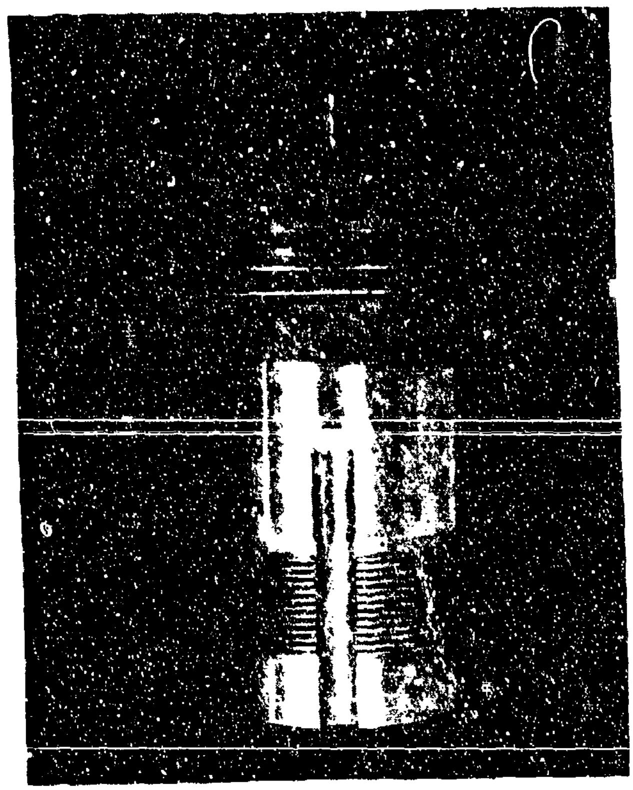

Figure 7. 152mm firing probe with Sandstrom 9A dry film lubricant.

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